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UNITED STATES
NAVAL POSTGRADUATE SCHOOL

DEPARTMENT OF AERONAUTICS

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CALIBRATION OF TORQUE AND THRUST

INSTRUMENTATION FOR THE BOEING TURBOPROP

by

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ABSTRACT

For the new set-up for torque and thrust measurements on the Boeing turboprop which was completed in April 1963, calibration was carried out by recording strain gage instrument readings for known torque moments and thrust loads.

Torque is applied by hanging weights at a measured distance from the center line of the flexure.

Thrust is applied with a "come-a-long" and read from a 1000 pound dynamometer.

Zero readings for torque and thrust are taken for the engine and engine stand with no added loads.

When torque and thrust are applied the loads are plotted against strain gage indicator readings.

The slope of the two curves is, in each case, constant, and the straight lines are actually a way of averaging out a number of test points each of which can be considered as the data for a torque or thrust factor.

The torque factor was found to be 0.464 Ft-Lbs per unit reading on the strain gage indicator.

The thrust factor was found to be 0.443 pounds per unit reading on the strain gage indicator.

1. INTRODUCTION:

The Boeing turboprop with a variable pitch propeller is mounted on a stand with casters. It is arranged that the stand can be secured to a concrete slab.

When the Boeing rig is used for laboratory classes static pressures are taken at a number of points, temperatures are taken by means of thermocouples, fuel flow is measured by a flow meter and data are taken for the calculation of air flow, the principal item of which is the static pressure at the throat of the bell-mouth. Engine and propeller RPM are also taken.

In order to make a more complete analysis of performance it is desirable to have torque and thrust measurements. An arrangement using strain gages is, from almost all standpoints, the best scheme.

Probably the best arrangement would be one where the thrust line goes through the thrust indicator linkage. In this particular set-up the linkage could not be in the line of thrust without interfering with the flow thru the bell-mouth.

Figure 1 shows, schematically, the general set-up. The engine thrust causes a moment in a vertical plane about the flexure. (The horizontal dimension of this plane contains the thrust line.) The thrust is countered by a moment in the same plane, the lever arm of which is the vertical distance between the load cell linkage and the center line of the flexure.

The torque is countered by a moment, the lever arm of which is the distance between beam-to-engine linkage and the center line of the flexure.

The flexure, while resisting other forces and moments, is very flexible relative to bending in the vertical plane that contains the thrust line and to the torsional moment due to engine torque.

Figure 2 shows the calibration set-up. The thrust is applied by a direct pull along the thrust line. The torque is applied by hanging a container at a distance of 2.67 feet from the center line of the flexure and placing shot bags in this container. Each shot bag is weighed before being placed in the container.

The instruments used for calibration are Baldwin strain gage indicators. In order to simplify procedure the type "L" instrument was always used for torque measurements and the type "M" for thrust. There

is practically no difference in these two instruments and the letters "L" and "M" were used just to distinguish between the two.

2. DISCUSSION:

A. For calibration it is necessary to have on hand the following equipment:

1. Two strain gage instruments. Baldwin strain gage indicators are used. The one designated as "L" type is connected to the strain gages on a ½" x 1" x 8" steel beam for torque readings. The "M" type indicator is connected to the load cell for thrust readings.

2. About 300 pounds of shot in 5 pound, 10 pound and 20 pound bags.

3. Scales to weigh the shot bags and the shot bag container accurately. (The container is hung from a notch 2.67 feet from the center of the flexure. The torque, then, is 2.67 times the weight of the shot bags plus the weight of the container.) Strain gage readings are taken at approximately 50 Ft. - Lb. intervals.

For thrust the equipment used is (as shown on Figure 2.) a 0-1000 pound dynamometer, a "come-a-long" and a tripod, the tripod out of 2" pipe tied to a concrete slab where ties have already been set in the concrete.

The torque calibration can be accomplished with two men, one of whom uses the strain gage indicator and records strain gage readings.

The thrust calibration needs three men, one to operate the "come-a-long", another to record dynamometer readings and a third to read the strain gage indicator at the time the dynamometer is read. (The pull will not stay constant for any length of time.)

Erroneous readings may result from relatively large, or even from small misalignments in the test set-up.

The discussion below, however, in paragraphs B and C, will be concerned only with the possibility of erroneous torque and thrust factors and not with the test rig set-up, although, in each case, errors may be caused by misalignment

B. Misalignment errors may be classified in three ways.

1. Torque or thrust.

2. Direct or indirect. These words are used in the following way: If an error in thrust application causes an error in the calculated thrust factor it would be a "direct" misalignment error. If an

error in thrust application causes an error in the caluclated torque factor, it would be an "indirect" error.

3. First or second order of magnitude. The paragraphs that follow indicate what is meant by this.

C. An investigation has shown that the most critical alignment problem is the alignment of the thrust in the horizontal plane. A small misalignment of thrust in the horizontal plane would have a small effect on thrust factor, but it would have a large effect on the torque factor.

Let the distance from the prop to the tripod be 12 feet, the distance used in the calibration.

Take an actual test point for the torque and thrust.

Torque = 334 Ft. - Lbs.

Thrust = 778 Lbs.

The distance from the flexure to the torque load linkage is 33".

Assume a misalignment error of one inch.

$1/12 \times 12 = 0.0698 = \arcsin 0.4^{\circ}$ $\quad \cos 0.4^{\circ} = 0.99997$

1. The error in thrust is then 0.003 of 1% which can be called an error of second order magnitude.

2. The error in torque would be (a component of thrust in the horizontal plane and perpendicular to the thrust would change the load on the beam-to-engine linkage and so the torque reading) an indirect misalignment error.

Load (pounds) thru the torque linkage

$334 \times 12/33 = 121$ pounds

$$\text{Error} = \frac{(\text{sin of angle of misalignment}) \times \text{Thrust}}{\text{Pull on Torque Linkage}}$$

$$= \frac{0.0698 \times 778}{121} = 0.0450$$

4.5% is definitely an error of first order magnitude.

D. Further investigation will show that this line of thrust in the horizontal plane is the one critical point of the whole set-up and that

this difficulty is inherent for any rig in which the thrust recording linkage is not in line with the thrust, the line of thrust being defined as a line through the center line of the propeller and perpendicular to the plane of the propeller.

Further, considering the question of torque and thrust recording from the standpoint of the set-up of the test rig as well as its calibration, it will be found that this same alignment problem is critical because of its effect on torque indication.

It might be questioned whether the flow due to the propeller thrust is, in fact, axisymmetric. Since the engine is symmetrical about a vertical plane the flow should be symmetrical about this plane. The rig is tested out of doors so there is a possibility of side winds. They are not frequent in the area used.

The engine is assymetric about the horizontal plane thru the thrust line. This assymmetry, and ground effect may cause a deflection of the flow either up or down. A small deflection would have only an effect of second order of magnitude both on the thrust and the torque. (A vertical component of thrust is perpendicular to the thrust line and perpendicular also to the line of the torque linkage).

4. RECOMMENDATIONS:

A. Calibration should be gone through again. This would not take a great deal of time since the procedure has been worked out in detail.

B. The dynamometer should be calibrated. A calibration curve could be made and used to correct dynamometer readings.

C. Special devices and special care should be used to insure that, in the test rig set-up, the thrust linkage exactly parallels the line of thrust and is in the same vertical plane.

D. Special devices and special care should be used to insure that, in the calibration set-up, the thrust linkage exactly parallels the line of thrust and is in the same vertical plane.

E. The possibility of using instrumentation other than the Baldwin strain gage indicators should be looked into.

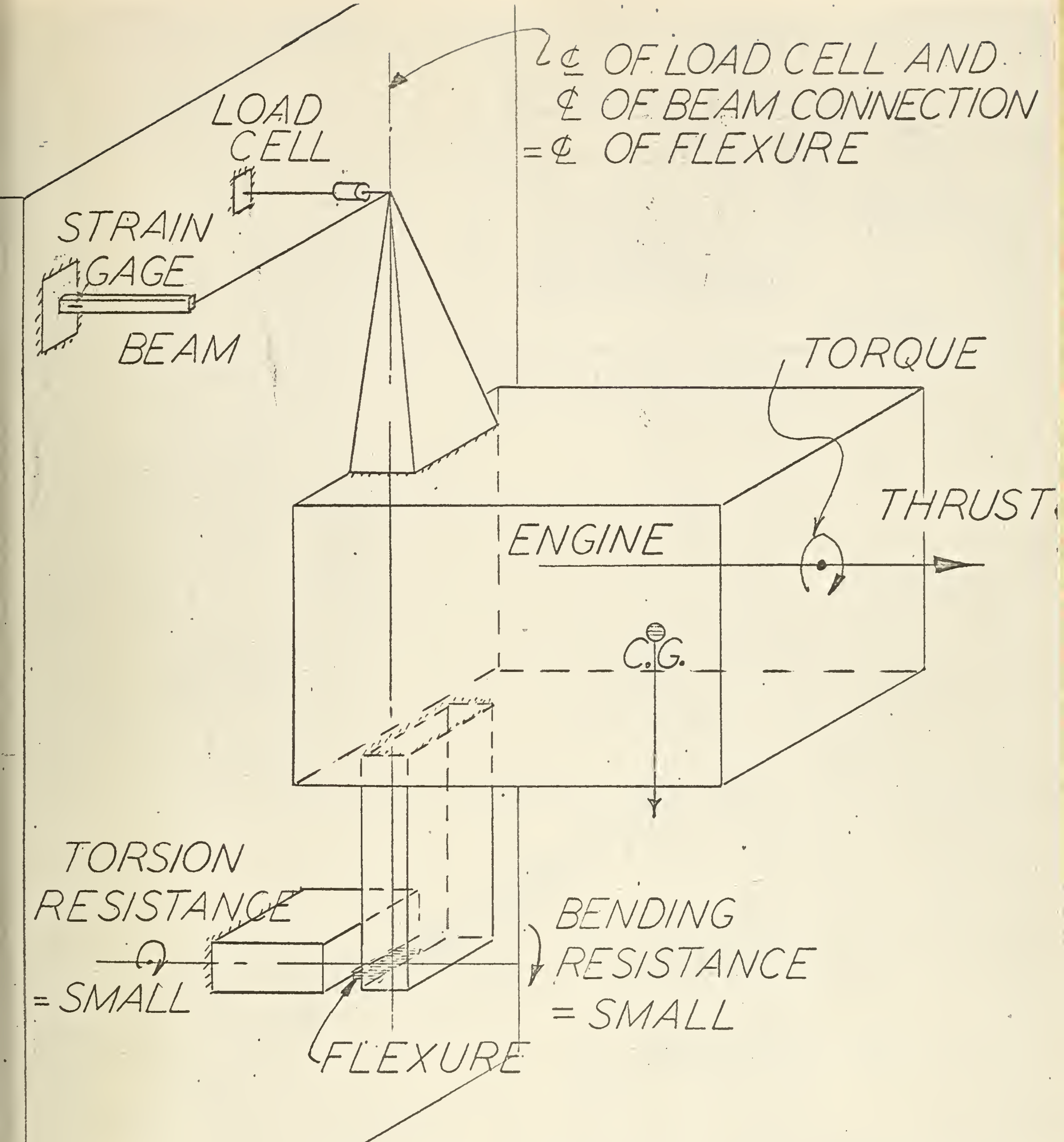


FIG. 1

SCHEMATIC OF TORQUE-THRUST ARRANGEMENT

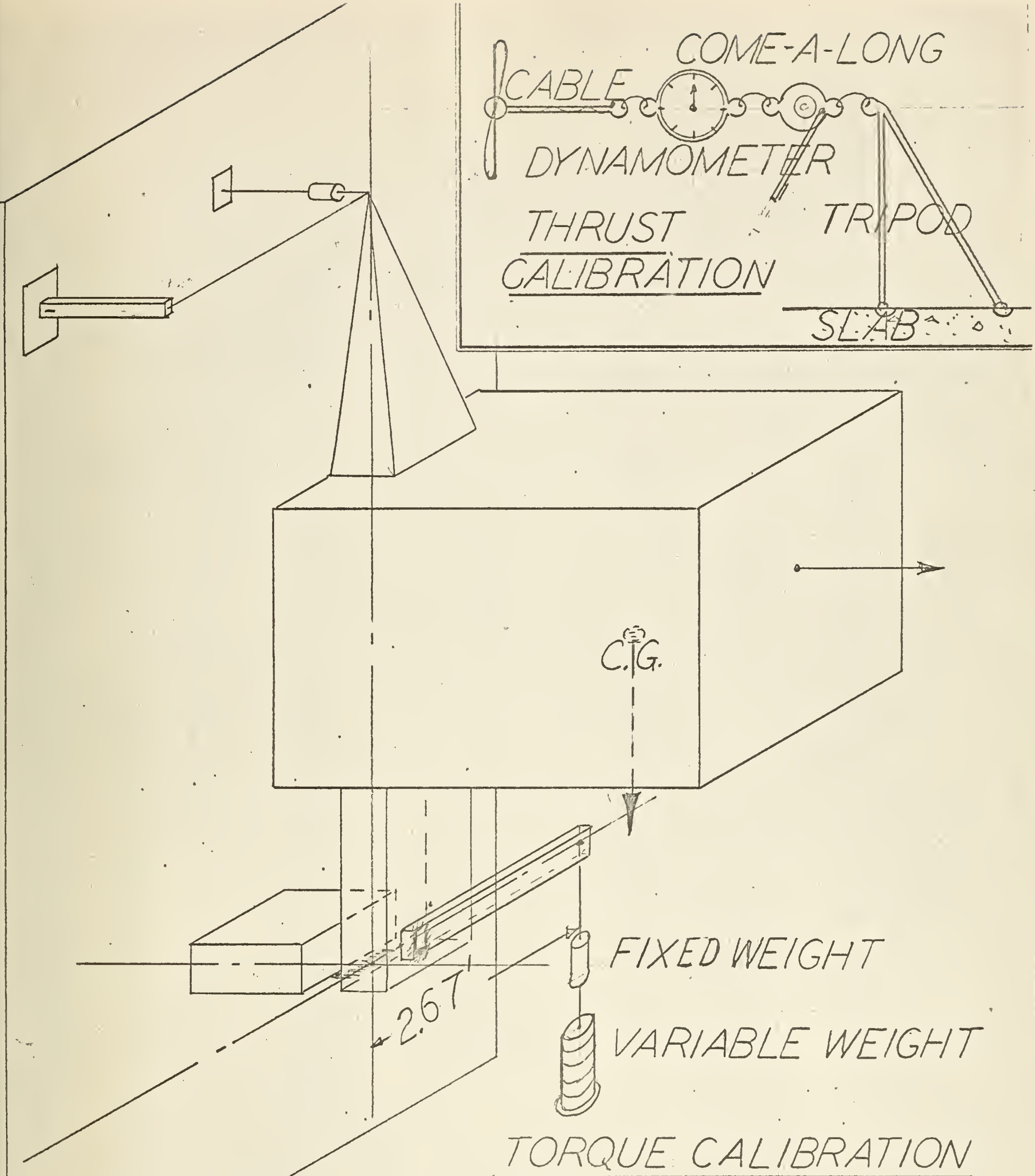
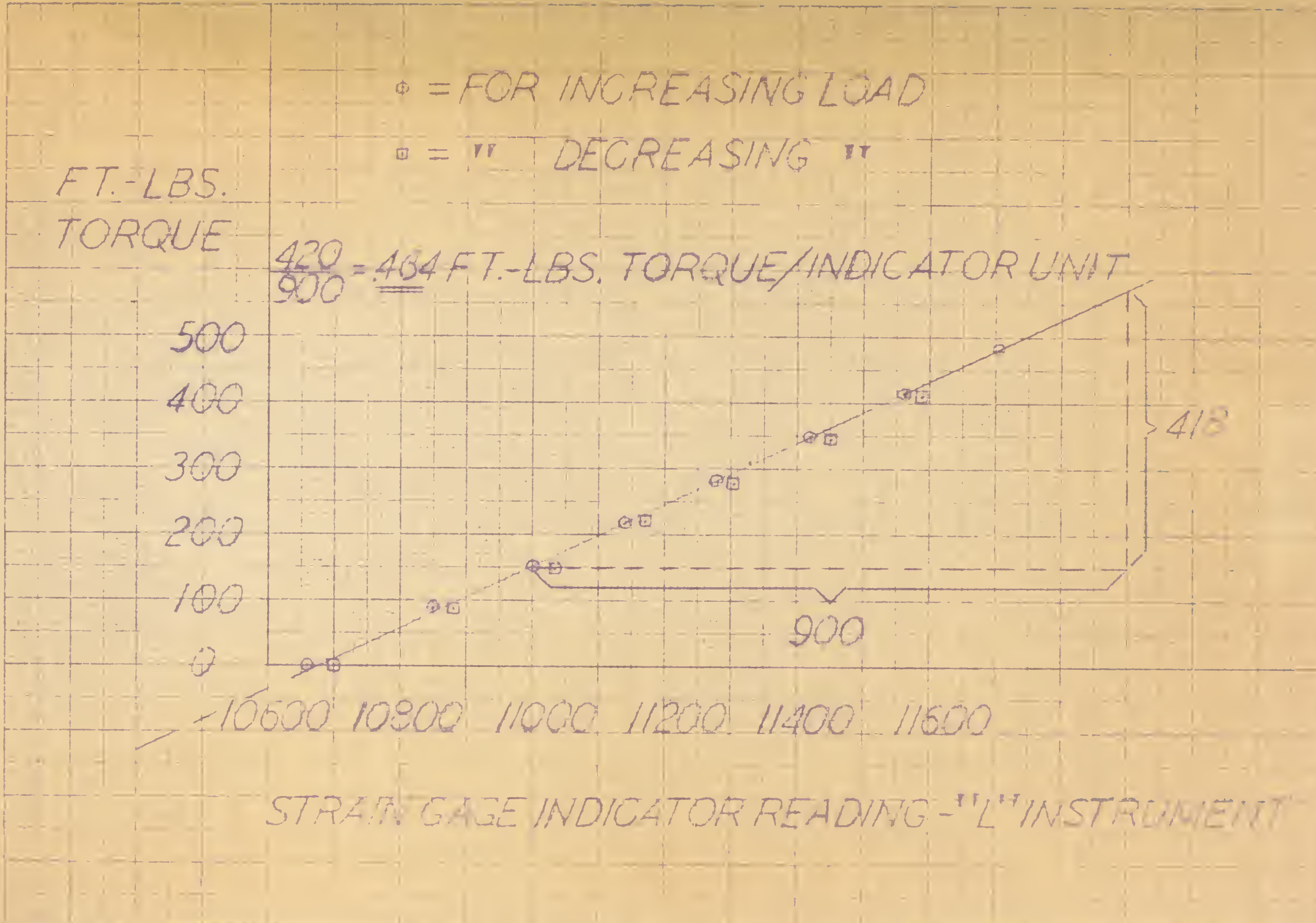
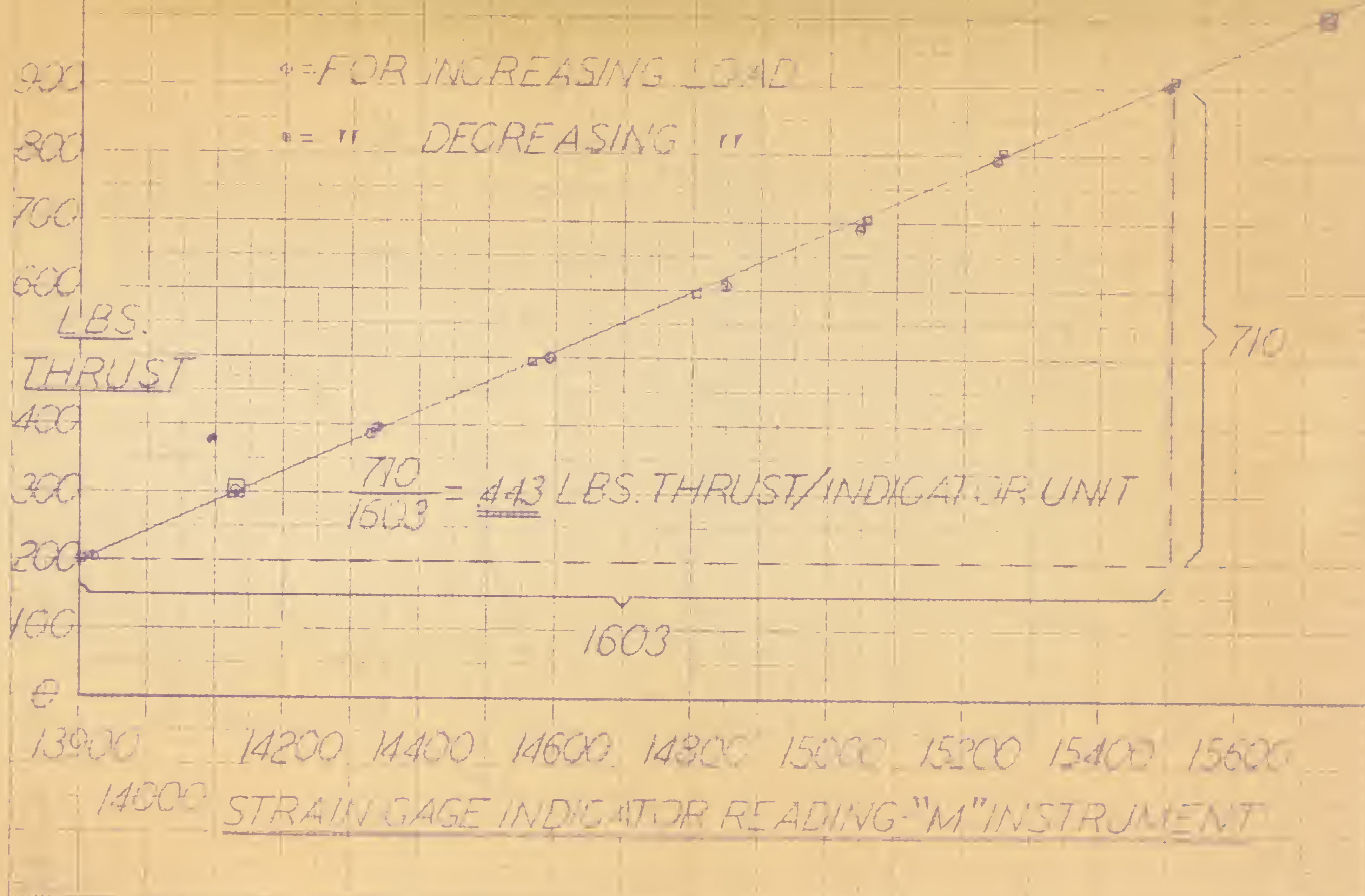


FIG. 2

CALIBRATION


⊕ = FOR INCREASING LOAD
⊡ = " DECREASING "
FT.-LBS.
TORQUE
420/900 = .464 FT.-LBS. TORQUE/INDICATOR UNIT
500
400
300
200
100
0
418
900
10600
10800
11000
11200
11400
11600
STRAIN GAGE INDICATOR READING - "L" INSTRUMENT



= FOR INCREASING LOAD
= " DECREASING "
LBS. THRUST
900
800
700
600
400
300
200
100
0
710/1603 = 443 LBS. THRUST/INDICATOR UNIT
710
1603
13900
14000
14200
14400
14600
14800
15000
15200
15400
15600
STRAIN GAGE INDICATOR READING-"M" INSTRUMENT

HP AT CONSTANT ENGINE RPM

$$HP = \frac{\text{TORQUE} \times 2\pi \times \text{RPM}}{33{,}000}$$

$$HP = \text{TORQUE} \times \text{RPM} \times 1.905 \times 10^{-4}$$

(WHERE RPM IS PROP RPM)

FROM DATA TAKEN APR. 18, '63

INDICATOR ZERO=10820

INDICATOR READING	PROP RPM	ENG. RPM	NET READ.	X .464	X .0001905	X RPM = HP
11945	1340	35600	1125	522	.0933	133
11845	1500	"	1025	475	.0905	136
11735	1800	"	915	423	.0806	145
11625	2100	"	805	473	.0712	150
11540	2400	"	720	334	.0637	153

ACCESSION NO.

U-90,285

Turboprop
Torque
Thrust
Measurement
Calibration

U 90285